Development of a Portfolio Management Approach with Case Study of the NASA Airspace Systems Program

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Abstract

A portfolio management approach was developed for the National Aeronautics and Space Administration's (NASA's) Airspace Systems Program (ASP). The purpose was to help inform ASP leadership regarding future investment decisions related to its existing portfolio of advanced technology concepts and capabilities (C/Cs) currently under development and to potentially identify new opportunities. The portfolio management approach is general in form and is extensible to other advanced technology development programs. It focuses on individual C/Cs and consists of three parts: 1) concept of operations (con-ops) development, 2) safety impact assessment, and 3) benefit-cost-risk (B-C-R) assessment. The first two parts are recommendations to ASP leaders and will be discussed only briefly, while the B-C-R part relates to the development of an assessment capability and will be discussed in greater detail. The B-C-R assessment capability enables estimation of the *relative value* of each C/C as compared with all other C/Cs in the ASP portfolio. Value is expressed in terms of a composite weighted utility function (WUF) rating, based on estimated benefits, costs, and risks. Benefit utility is estimated relative to achieving key NAS performance objectives, which are outlined in the ASP Strategic Plan.[1] Risk utility focuses on C/C development and implementation risk, while cost utility focuses on the development and implementation portions of overall C/C life-cycle costs. Initial composite ratings of the ASP C/Cs were successfully generated; however, the limited availability of B-C-R information, which is used as inputs to the WUF model, reduced the meaningfulness of these initial investment ratings. Development of this approach, however, defined specific information-generation requirements for ASP C/C developers that will increase the meaningfulness of future B-C-R ratings.

Nomenclature

ARMD = Aeronautics Research Mission Directorate
ASP = Airspace Systems Program
ATC/M = Air traffic control/management
ATD = Advanced technology demonstration
B-C-R = Benefit-cost-risk
C/C = Concept/capability
Con-ops = Concept of operations
DOD = Department of Defense
FTE = Full-time equivalent (i.e., single Federal Civil Servant person-year effort)
FY = Fiscal year
NAS = National Airspace System
NASA = National Aeronautics and Space Administration
NRA = NASA Research Agreement
O&S = Operating and support
R&D = Research and development
RI = Research investment
TRL = *Technology readiness level*
WUF = Weighted utility function
WYE = Work-year Equivalent (i.e., single on-sight contractor person-year effort)

Introduction

The Airspace Systems Program (ASP) desired a systematic and traceable process for assessing the value of its research investment (RI) portfolio in terms of estimated benefits-costs-risks (B-C-Rs). (**Note:** B-C-R assessments are commonly used by NASA to estimate the value of its technology development efforts.) An RI corresponds to a committed development effort (typically several years in duration) of an advanced air traffic control or management (ATC/M) concept or capability (C/C), toward potential deployment in the National Airspace System (NAS). This process will help the ASP match its resource allocation decisions (e.g., workforce, research facilities, procurement) to the work scope and schedule for each RI. The ASP likewise has need of guidance regarding decisions to accelerate or decelerate the pace of C/C development, based on stakeholder priorities related to the order of, and timeframes for, operational deployment.

The ASP is one of four research programs under NASA's Aeronautics Research Mission Directorate (ARMD). Each program defines key strategic objectives in its respective strategic plan. For the ASP, these key objectives have been articulated as: *"The primary technical objectives...are to enable significant increases in capacity/throughput and efficiency, while maintaining safety."* Capacity, throughput, and efficiency constitute the benefits that ASP C/Cs seek to safely achieve, while cost and risk are to be managed appropriately to maximize the

overall composite B-C-R rating of each C/C. Safety of operation was addressed separately from the B-C-R assessment and will be discussed only briefly herein.

This study was undertaken to provide an initial composite B-C-R rating for each C/C relative to all others in the ASP portfolio. The current ASP portfolio was formulated prior to establishing this B-C-R rating capability; consequently, it was expected that many of the C/Cs would lack the required data to produce meaningful ratings for this initial assessment. Acknowledging this, three principal outcomes were pursued: a) defining the set of information required to effectively rate each C/C, b) determining the current availability of this information, and c) assessing the gap between the required and currently available information to understand the magnitude of effort required to generate the full information set to support future B-C-R assessments. Based on the answer to outcome c), ASP leadership would then decide whether to require C/C developers to generate the required information, either in whole or in part, to support this assessment effort.

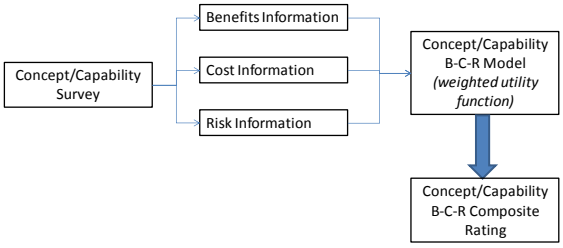
Study Approach

The decomposition approach used to assess the composite B-C-R value of the ASP C/C portfolio is commonly used within NASA. It is simple, direct, intuitive, and consists of the following steps:

1. Define the B-C-R dimensions (including metrics).
2. Complete logical decompositions of each dimension into its component parts for use in a weighted utility function (WUF) model.
3. Formulate a Web-based survey to elicit required B-C-R information from C/C developers for inputs to the WUF model.
4. Prepopulate surveys using available C/C project literature.
5. Review prepopulated surveys with corresponding C/C developers to comprehensively and accurately catalog the available B-C-R information.
6. Populate the WUF model to generate initial composite B-C-R ratings.

The C/C rating process is outlined graphically in Exhibit 1 and will be discussed in greater detail below.

Exhibit 1. Benefit-Cost-Risk Rating Process



Benefits are expressed in terms of the key ASP strategic objectives to increase capacity/throughput and efficiency of the NAS, while maintaining safety. The benefit dimension comprises two major elements: capacity/throughput and efficiency, which are commonly used NAS performance measures within the ATC/M research community. Maintaining NAS safety was treated as a constraint on new C/Cs in achieving increased capacity/throughput and efficiency.

Each of the two benefit elements required a detailed definition and corresponding metric(s) assignment and was logically decomposed into its more detailed component parts. While the definitions and corresponding metrics for this study are NASA-defined, they are also commonly used in research studies by the broader ATC/M research community.

Throughput is defined as the number of flights in the gate-to-gate NAS that transit either a point or interval of distance (interval can vary between a short distance to NAS-wide), over a specified time period (e.g., hour, day, year, and so on) Typical throughput measurement units include flights per quarter hour, flights per hour, flights per day, and so forth.

Capacity is defined as the throughput level that corresponds to a fixed delay threshold for a given set of flights. Delay is measured relative to unimpeded flight time (i.e., flight times unimpeded by congestion, weather, and all other throughput-impeding sources) over the flight interval of measurement. Capacity metrics are the same as throughput metrics but have an additional qualifier that specifies the delay threshold level. Examples of delay thresholds include 15 minutes of average delay for a schedule of flights, a maximum of one hour of delay for any individual flight within a schedule of flights, and so forth.

The *efficiency* benefit is fundamentally defined as the level of desired output per unit of required input (or cost) to achieve that desired output. Three measures of flight trajectory efficiency were initially considered: time, distance, and fuel efficiency. Upon further consideration, time efficiency—or the time required to transact a flight or schedule of flights—had the same metric as throughput (i.e., flights per unit time), which was already being measured.

Increased time efficiency also can be expressed in terms of reduced flight delay, with a 100 percent time-efficient flight time being equal to its unimpeded flight time. Exhibit 2 illustrates the tradeoff between throughput and time efficiency (expressed in terms of delay) benefits. As can be seen in exhibit 2, advanced ASP C/Cs can reduce throughput impedance to a) enable additional throughput at a fixed delay level, b) hold throughput constant and reduce flight time (delay), or c) some combination of both. Distance efficiency is indirectly accounted for through its functional relationship with both time and fuel efficiencies, which are the primary efficiency benefits of interest to the NAS stakeholders (e.g., the flying public, airlines, package shippers, and so on). Consequently, only fuel efficiency remained after consideration of the initial three efficiency measures and can be defined for an individual flight, as well as for a schedule of flights (i.e., fuel consumed per flight or per schedule of flights).

Risk was decomposed into development and implementation risk. *Development* risk is defined as the risk that the target performance level of a particular C/C *will not* be successfully achieved. *Implementation* risk is the conditional risk that, given successful development, the C/C *will not* be successfully deployed in the NAS.

The cost decomposition was based on Department of Defense (DOD) guidance[2] that has been tailored appropriately to evaluate NASA ASP RIs. Similar to risk, cost was decomposed into development and implementation branches, with implementation costs further decomposed into investment and operating and support (O&S) costs. Cost is used in Exhibit 3 to illustrate the logical decomposition format, while the benefit and risk decompositions are provided in Appendix A.

Exhibit 2. Concept/Capability Throughput and Delay Benefits

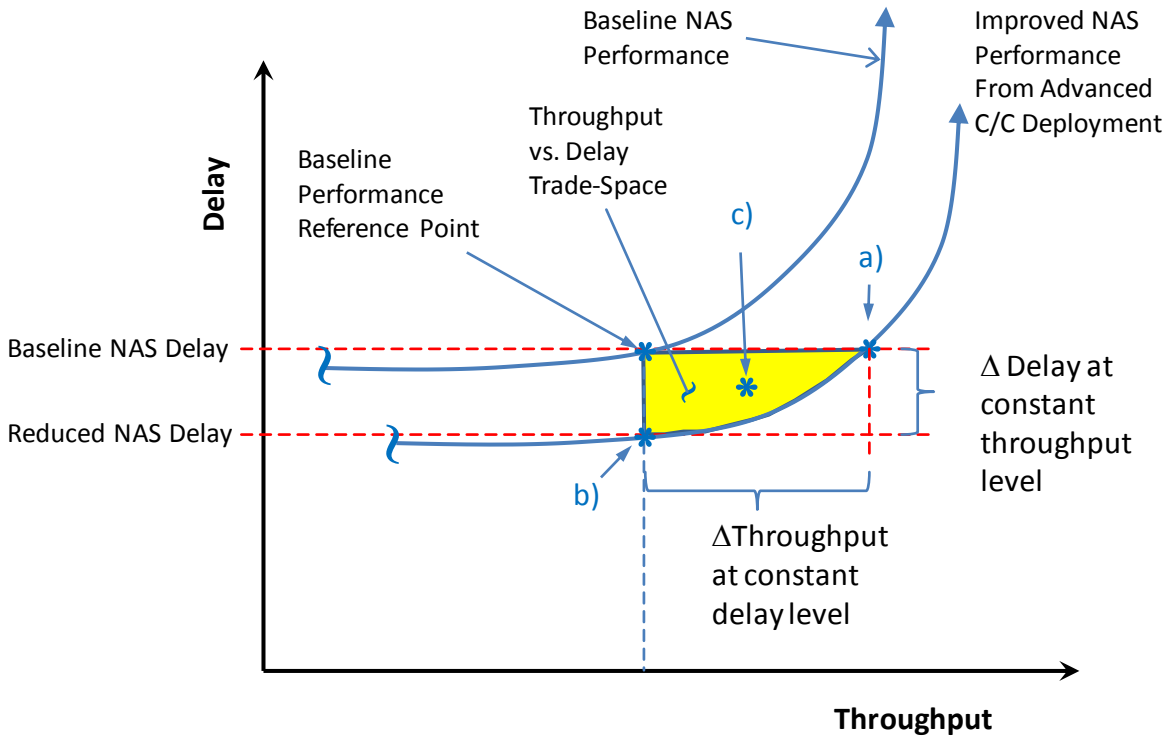
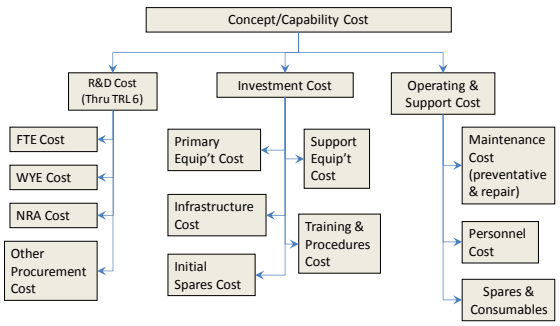


Exhibit 3. Concept/Capability Cost Decomposition



Note that a primary constraint in developing the logical decompositions—starting at the top level—was to be comprehensive and efficient in classifying all relevant contributors below, to the decomposition level above, particularly for the top two levels. The bottom decomposition level was reached, where sufficient detail existed for C/C developers to map their B-C-R characteristics to the relevant decomposition elements there. For example, referring to the Exhibit 3, *R&D Cost* (through technology readiness level (TRL 6)) branch; elements listed there under compose the entire spectrum of cost categories available to the ASP to resource the development of each C/C. The ASP tracks these cost categories annually, and the data are available to populate the WUF model for each C/C accordingly. The other two branches, *Investment Cost* and *Operating & Support Cost*, are not borne by NASA; consequently, the ability of C/C developers to accurately estimate these costs is limited compared with R&D costs. Other methods are being explored (currently with the FAA) to adequately estimate these costs. For now, implementation cost estimates are based on qualitative estimates, which are based on required changes to the current ATC/M systems, architecture, training, and procedures to accommodate the new C/C.

The ASP annually documents its full portfolio of RIs via milestone records that describe the scope of C/C development for that year, including detailed work tasks, required resources, and exit criteria to be satisfied. These records were reviewed for fiscal year 2012 (FY12) to infer the specific C/Cs under development within the ASP, and a total of 23 were identified. Milestone record information was used to initially populate the C/C surveys, which were designed to elicit required inputs to the WUF model. Once initially populated, the surveys were reviewed with cognizant C/C developers to clarify, correct, and add B-C-R information, as appropriate, prior to input into the WUF model.

The life cycle of ASP C/C development typically follows a multi-year progression along the nine-level TRL scale[3], typically beginning at TRL 1 or 2 (Exhibit 4 describes NASA's TRL levels). NASA's ASP typically transitions its advanced C/Cs at TRL 6 or 7 for further progression through TRL 9 by other entities (often collaboratively with NASA). A subset of C/Cs progress through TRL 7 within the ASP via an advanced technology demonstration (ATD), while most cease maturation at TRL 6. Note that although NASA's ASP does not lead the C/C transition from TRL 6 or 7 through TRL 9, the Agency is keenly interested in the successful transitioning of its C/Cs through this interval. Consequently, to maximize the likelihood of successful NAS deployment of its C/Cs, NASA attempts to consider all important criteria related to this transition through TRL 9 while it matures them within the ASP through TRL 6 or 7.

As previously indicated, the portfolio management approach included recommendations to ASP leaders regarding con-ops development and safety impact assessments for individual C/Cs, as well as integrated combinations thereof. A con-ops is required to support the various analytical assessments of C/Cs as they are matured within the ASP. It was recommended that an initial con-ops be developed at approximately TRL 2 or 3, once the ASP has decided to commit to further C/C development. The con-ops would then be matured with the C/C along the TRL progression toward transition level 6 or 7. Similarly, an initial safety impact assessment was recommended at approximately TRL 2 or 3, with a second assessment at TRL 6 once the C/C was defined in greater detail and deemed ready for transition to either an ATD or operational NAS deployment.[4] The purpose behind the safety impact assessments is to build safety into the

Exhibit 4. NASA Technology Readiness Level Definitions

TRL 1 Basic principles observed and reported Basic scientific research that can be turned into an application or a concept under a research and development program is considered.	**TRL 2** Technology concept or application formulated An idea is proposed for the practical application of current research, but there are no experimental proofs or studies to support the idea.	**TRL 3** Concept or application proven through analysis and experimentation Active research and development begins, including analytical laboratory-based studies to validate the initial idea, providing an initial "proof of concept."
TRL 4 Basic prototype validated in laboratory environment Basic examples of the proposed technology are built and put together for testing to offer an initial vote of confidence for continued development.	**TRL 5** Basic prototype validated in relevant environment More realistic versions of the proposed technology are tested in real-world or near real-world conditions, which includes initial integration at some level with other operational systems.	**TRL 6** System or subsystem model or prototype demonstrated in a relevant environment A near final version of the technology in which additional design changes are likely is tested in real-life conditions.
TRL 7 System prototype demonstrated in a relevant environment The final prototype of the technology that is as close to the operational version as possible at this stage is tested in real-life conditions.	**TRL 8** Actual system completed and qualified for flight through test and demonstration The technology is thoroughly tested and no further major development of the technology is required. Its operation as intended is demonstrated without significant design problems.	**TRL 9** Actual system proven through successful operation. The final operational version of the technology is thoroughly demonstrated through normal operations, with only minor problems needing to be fixed. Any further improvements to the technology at this point, whether planned or not, will be treated as a TRL 1.

C/Cs from inception through transition at TRL 6 or 7.

Analysis Methods

The WUF model used the following weighted utility function:

$$U_g(X) = \sum_{i=1}^{n} k_i U_i(x_i) \qquad (1)$$

where

$U_g(X)$ = overall utility rating for designated B-C-R dimension *g* for C/C *X*

$U_i(x_i)$ = utility of the *i*th measure of dimension *g* for C/C *X*

k_i = weighting of the *i*th member of dimension *g* for C/C *X*

B-C-R information from each C/C survey was translated by WUF model analysts into utility rating estimates assigned to all applicable elements in the B-C-R decompositions (typically assigned at the bottom two levels of the decompositions). These ratings were based on appropriate quantitative data when available; otherwise, the ratings were based on qualitative, experience-based judgment by analysts with review and concurrence by C/C developers. Utility estimates were summed across each decomposition level to represent the aggregate utility at the next level up in the decomposition. This upward aggregation approach continued to eventually culminate in the top-level composite B-C-R rating for each C/C. Each utility rating, assigned at the bottom two levels, ranged from zero to one corresponding to zero and *maximum* utility respectively. For the benefit dimension, maximum utility corresponds to maximum benefit. For the cost and risk dimensions, maximum utility corresponds to *minimum* values for each. For each decomposition element at the bottom two levels, a maximum utility rating of *one* was assigned to the C/C with the highest estimated utility for that element. All other C/Cs impacting that element, were assigned ratings between zero and one, proportional to the ratio of their estimated utility, to that of the highest utility C/C. Consequently, the ratings represent a relative ranking among the 23 C/Cs rather than relative to any absolute reference (e.g., some theoretical B-C-R limit), or relative to other C/Cs under development outside the ASP.

Weighting factors express the relative contribution of each element in a given decomposition branch, compared with all other elements in the same branch and at the same decomposition level, to the next level up. Weighting factors can be estimated analytically by completing sensitivity assessments of higher level elements, to variations of each contributing element at the next decomposition level down. Analytical estimation requires an analytical model that represents the functional relationship between decomposition-level elements. The ASP possesses such models in certain cases, but in others a qualitative weighting factor assignment must be provided by ASP leaders based on experience-based knowledge of the NAS's operational dynamics. For this initial portfolio assessment, weighting factors were all set to unity (i.e., equally weighted for all decomposition elements) with the expectation that ASP leaders would use their judgment to assign appropriate values. Future assessments will attempt to employ analytical models to help set weighting factors based on data-driven sensitivity assessments where appropriate.

Conclusions

C/C surveys were pre-populated by using project milestone records, which contained incomplete B-C-R data. Limited follow-up discussions with some C/C developers to date have provided some additional information, and the ratings below reflect this limited data set. Note that some rating bars are missing data in one or more of the listed B-C-R dimensions; in such cases, the utility rating assigned was zero (i.e., minimum utility). Exhibit 5 shows the overall B-C-R ratings for the 23 C/Cs that were assessed.

Exhibit 5. Concept/Capability Overall B-C-R Rating

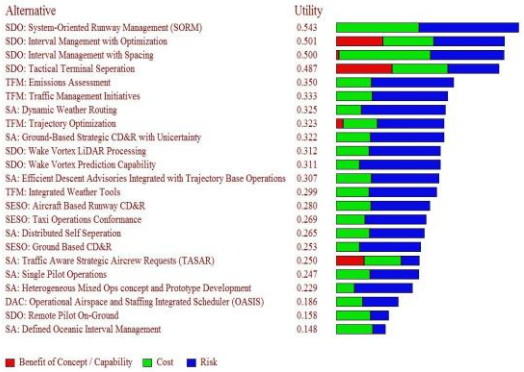


Exhibit 6 shows the benefit rating of the C/Cs. Note that only four of the C/C/s provided any benefit information in the project documentation.

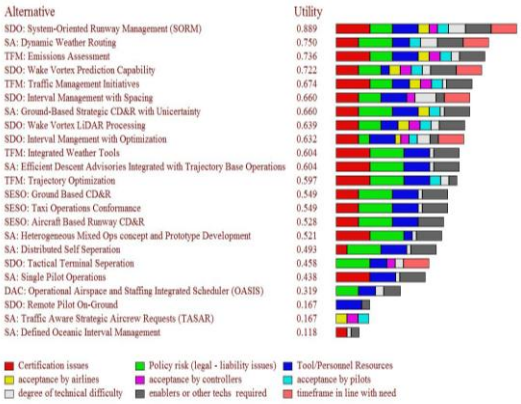
Exhibit 6. Concept/Capability Benefit Rating

Exhibit 7 shows the cost rating for the C/Cs; noteworthy is the inverse relationship between cost utility and cost. The cost utility *increases* as the development and implementation costs of a C/C *decrease*. The survey elicited development cost information for prior development years (i.e., sunk cost) as well as for the current year, and projected future yearly costs through TRL 6 maturity. Implementation costs were qualitatively estimated based on anticipated deployment characteristics by the C/C developers, including infrastructure, system hardware and software, regulations, training requirements, and the like.

Exhibit 7. Concept/Capability Cost Rating

Exhibit 8 shows the risk ratings for the 23 C/Cs; similar to the cost ratings, the relationship between risk utility and risk is an inverse one. The higher number of segments in the risk rating bars *appears* to indicate that project documentation provided more risk information than benefit or cost information, which was not the case. Instead it proved easier to provide an intuitive, experience-based estimate for the risk decomposition elements than for the benefit and cost decompositions. Benefit and cost rating estimates at the lowest decomposition levels required more quantitative data analysis than the risk dimension.

Exhibit 8. Concept/Capability Risk Rating

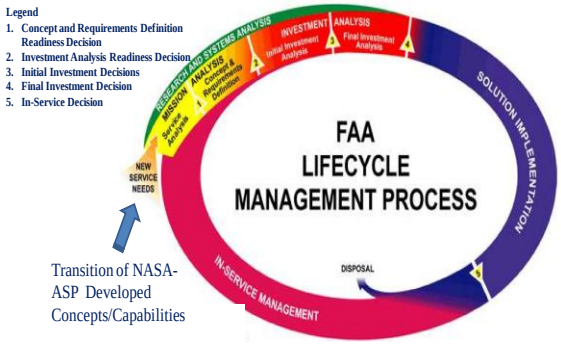


Recommendations

Several recommendations were made to ASP leaders as a result of this study. These are listed below.

1. Generate and disseminate the required C/C information to populate the B-C-R model and enable ratings with significantly greater meaning.
   a. C/C developers respond annually to the Web-based C/C survey and provide the requested information that is currently available.
   b. For information *not* currently available, developers should include in their C/C development plans the generation of the required B-C-R information to support this assessment.
2. To potentially increase the likelihood of NAS deployment for ASP C/Cs (i.e., transition from TRLs 7 through 9), generate information and systems analysis while maturing ASP C/Cs through TRLs 6 and 7, to complement the research and systems analysis required by the FAA's Life Cycle Management Process, which is shown in Exhibit 9. [5]

Exhibit 9. FAA Life Cycle Management Process



3. Develop an initial con-ops and safety impact assessment for each C/C, or an integrated set thereof, at approximately the TRL 2 to 3 level.
4. Mature the con-ops and C/C through TRLs 6 and 7, and complete a second safety impact assessment at TRL level 6.

Acknowledgments

The authors would like to acknowledge Mr. H. P. Tosoc and Ms. S. A. Brown from NASA Langley Research Center, for their important contributions to this portfolio management development effort.

References

[1] Next Generation Air Transportation System Concepts and Technology Development Project, "FY2011-2015 Project Plan," Version 3.0, NASA, Airspace Systems Program, April 5, 2011.

[2] Department of Defense, "Cost Analysis Guidance and Procedures," DOD 5000.4-M, December 1992.

[3] Mankins, J. C., "Technology Readiness Levels; A White Paper," NASA, Advanced Concepts Office, Office of Space Access and Technology, April 6, 1995.

[4] Fuchs, A., Kozarsky, D., and Creaghan, S., "Safety Assessments of ATM R&D Projects," AIAA 2005-7429, September 2005.

[5] Federal Aviation Administration, Investment Analysis and Planning Organization AFI-1, "Acquisition Management System Guidance, Investment Analysis Process Guidelines," March 2012.

Appendix A
Benefit-Cost-Risk Decompositions

Exhibit A-1. Capacity Benefit Decomposition

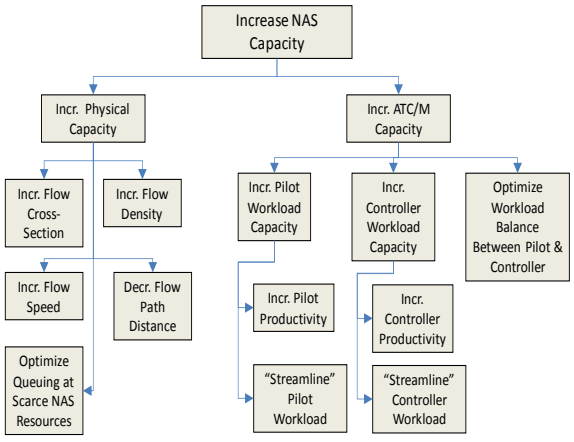


Exhibit A-2. Fuel Efficiency Benefit Decomposition

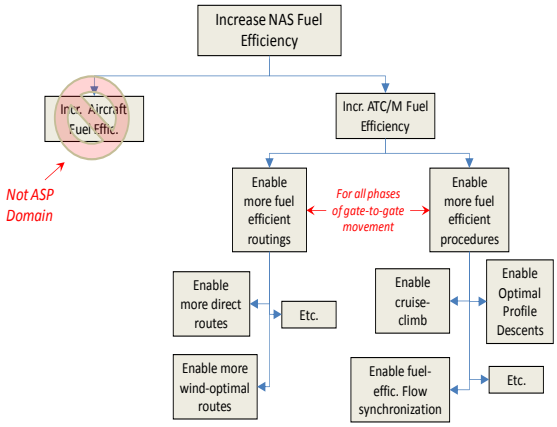


Exhibit A-3. Risk Decomposition